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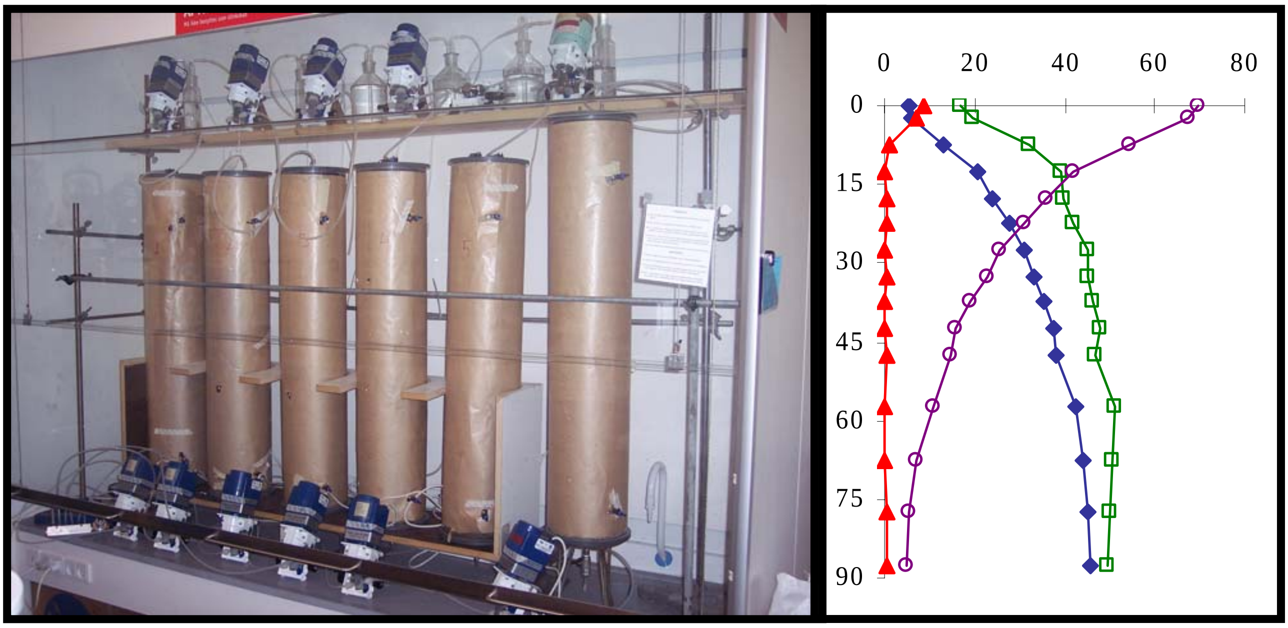
Publication date:
2008

Document Version
Publisher's PDF, also known as Version of record

BIOCOVER



Testing Improvement Strategies

Department of Environmental Engineering
University of Denmark

January 2008

BIOCOVER

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January 2008

Preface

The full title of the BIOCOVER project is *Reduction of Greenhouse Gas Emissions from Landfills by use of Engineered Biocovers*. The project is funded by the LIFE III ENVIRONMENT program, the Danish Environmental Protection Agency, and RENOSAM and runs from August 2005 to November 2008. This report presents the outcome of Task 4 *Testing Improvement Strategies* (deliverable D.4.3.1) as described in the project application (Biocover, 2005). Fakse Landfill serves as the demonstration landfill for the BIOCOVER project.

Summary

The aim of task 4 is to find an appropriate material for the full scale field trial biocover system at Fakse landfill. Initially the available materials at the site were evaluated and 7 different materials were identified; Fine compost of garden waste, 1-2 years old **(FC)**, Raw compost of garden waste, 1-year old (**RC1)**, Raw compost of garden waste, 3-4 years old **(RC4)**, Raw compost of garden waste, 7-9 years old **(RC8)**, Sewage sludge compost **(SC),** Sieving residue, 1year old **(SR1)** and sieving residue, 3 years old **(SR3).** The availability of the materials were assessed and they were characterized chemically and by methane oxidation and respiration tests. After 3 repetitions of the batch test to secure adaption the following methane oxidation rates were achieved with the highest first; SC (130.1μg/gDM/h), RC4 (74.9 μg/gDM/h), FC2 (44.4 μg/gDM/h), SR3 (35.6 μg/gDM/h), SR1 (11.4 μg/gDM/h) and RC8 (7.4 μg/gDM/h). Also the oxygen demand of the compost themselves were measured in separate experiments. This is believed to have an effect as there will be competition for oxygen to methane oxidation and respiration. The SC was found to have a rather high oxygen demand (122.3 μg/gDM/h), which was not the case for the RC4, which had an oxygen demand of only 3.8 μg/gDM/h due to its high age. Also the screening residues had rather high oxygen demands of 95.2 μg/gDM/h and 66.1 μg/gDM/h for the SR1 and the SR3 respectively. Five materials were chosen for further investigation based on 5 different parameters; Potential methane oxidation rate, oxygen demand, porosity and gas permeability, availability and price.

It was found that a 5000 m^3 of material were needed due to the high methane emissions rate at Fakse landfill found in Task 3. It was therefore decided that adding sandy materials to the Biocover windows was too expensive. Furthermore materials with limited availability would not be very relevant to test. It was chosen not to test the RC8 further due to its very low potential for methane oxidation and its limited availability. Furthermore it was chosen not to test the SR3 due to its limited availability and its relatively low methane oxidation rate. The 5 remaining materials were tested in column experiments with a load of app. 200 g/m^2/day and achieved the following average methane oxidation rates over the 4 month test period; FC 120 g/m^2/day, SC 112 g/m^2/day, RC4 108 g/m^2/day, RC1 52 g/m^2/day, SR1 45 g/m^2/day. Most of the materials followed the oxidation pattern which has previously been seen in the literature with an increase in the oxidation rate in the beginning of the experiment followed by a decrease. Though this was not the case for the SR which had an increasing rate during the entire time of the experiment. The material with the highest methane oxidation rate in the end of the experiment was also the fine compost, which seemed to enter a second increase. Gas profiles indicated lowered permeability over time as nitrogen and oxygen diffused lower into the column in the end of the experiment and methane oxidation seemed to take place higher in the column in the end of the experiment.

When deciding upon which compost should be used in the field scale biocover up-dated availability of the composts were achieved, April 2007. An additional source of RC4 and SR3 (4000m^3) was dug out in unit 6 at the landfill and therefore the availability of these materials was increased. Based on these findings, the higher price of the FC (needs sieving) and the fact that the SC can be used in agriculture it was chosen to use the RC4 in the full scale biocover system. As app. 1000m^2 of RC4 was missing SR3 was used also, because it had similar qualities.

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Introduction

Most landfills contain organic wastes which produce biogas, containing methane and carbon dioxide. Emission of methane from landfills is a serious environmental problem and is explicitly mentioned as a source for greenhouse gasses in the EU *Sixth Environmental Action Plan*. In a global perspective, landfills accounts for 7-20% of the anthropogenic methane emissions to the atmosphere.
Landfill gas (LFG) is at some landfills extracted and utilized for energy purposes leading to methane emission reduction. However, it is not always feasible to extract and utilize the landfill gas. In these cases the gas is flared with risk of producing toxic combustion products, or is just escaping to the atmosphere.
A low-cost alternative could be to improve the top covering of the landfill in order to optimize the biological methane oxidation in the cover. Laboratory experiments have documented that a very high methane oxidation rate can be obtained in bio-covers, thereby reducing the methane emission significantly. The biological methane oxidation transforms methane into carbon dioxide, and since methane has a 21 times stronger global warming potential than carbon dioxide, a significant reduction in the source to global warming is obtained. Biocovers may also be a very cost-effective supplementary method at landfills with landfill gas utilization, since the efficiency of the gas extraction system often is in the range of 50-60 %.
The BIOCOVER project has the objective to perform a full scale implementation of engineered bio-covers and to document the methane reduction efficiency. Fakse Landfill in Southern Zealand, Denmark, serves as a demonstration landfill for the implementation of the technology.
Fakse Landfill is divided into two sections. The oldest section which was in use from 1981 until 1997 will be the focus of the project activities. This part of the landfill has an area of 12 hectares and has received mixed waste. Approximately 600,000 tonnes of waste has in total been disposed of at the older part of the landfill. The landfill is typical for Danish landfills of similar age.

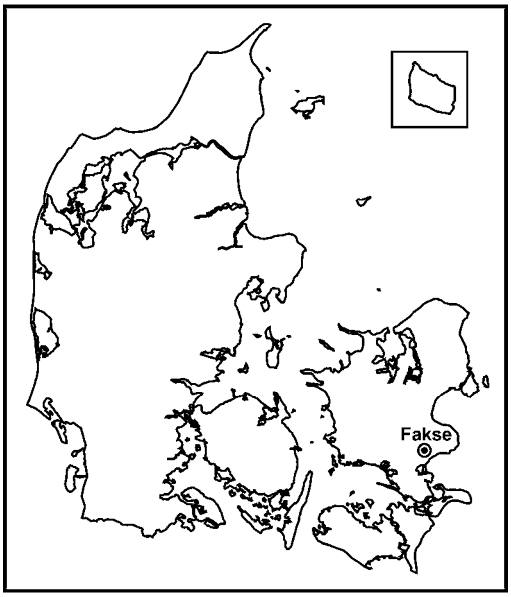

Figure 1. Map of Denmark showing the location of the study landfill, Fakse Landfill

This report concerns the testing of the improvement strategies (Task 4). The main purpose of this report is to decide which cover material should be used in the full scale demonstration biocover system and determine the efficiency of the material in the laboratory in order to give an idea of the expected field methane oxidation rates. The task and the report is divided into the 3 sub actions, Action 4.1 Overview of available cover materials, Action 4.2 Characterization of materials and quick test determination of the methane oxidation capacity and finally Action 4.3 Cover performance lab testing. Furthermore the report has a paragraph on how the final choice of the material for the full scale biocover is done.

Action 4.1 Overview of available cover materials

An overview of the available quantities of organic materials to be used for establishment of the biocover system at Fakse Landfill is presented below. Furthermore, a listing of prices for additional inorganic materials that can be bought locally is presented.

Organic materials

Two types of compost are produced at Fakse Landfill; (1) compost made from garden waste and (2) compost made from sewage sludge mixed with straw and garden waste. The latter type has to be disposed of for agricultural use according to the Danish “sludge executive order” (slambekendtgørelse), though as good results are expected and there is a possibility to get a dispensation it is chosen to run experiments with the material.
The quantities of the two compost types produced at Fakse Landfill in 2006 are seen in Table 1.1 together with quantities of compost materials stored at Fakse landfill in April 2006. These are the amount used when deciding, which compost types should be tested. Later on in April 2007 additional piles of Raw Compost and Screening Residue was dug out and this knowledge was used when deciding upon the final material for the full scale biocover.
Sorting of the raw compost takes places continuously; hence the current finished compost has been sorted continuously within the last 6 months. The garden waste has normally been received 12-15 months prior to the time of sorting (I/S FASAN, 2006a).

Table 1.1. Quantities of compost materials produced 2006 and stored at the composting facilities at Fakse Landfill 2006 (I/S FASAN, 2006a and b).

Compost materials	Quantity tonnes/year	Comment
Compost from garden waste		
Raw Compost	10.000	Production in 2006
Fine Compost	7.000	Production in 2006
Screening Residue	3.000	Production in 2006
Compost from sludge, straw and garden waste		
Sorted Compost	7500	Agricultural disposal prescribed
Stored compost at the site, April 2006		
Fine Compost (0-6months)	2000ton	(0,64ton/m^3) => 3125m^3
Raw Compost	8000m^3	Two finished madras’s of 4000m^3
Raw Compost 4 years	100m^3	Eastern part of the landfill (unit 1)
Raw Compost 8years	450m^3	Southern part of landfill (unit 6)
Screening Residue 3years	450m^3	Southern part of landfill (unit 6)
Stored compost at the site, April 2007[a]		
Raw Compost, including screening residue >5years	4000m^3	Southern part of landfill (unit 6)
Raw compost 2years	800 m^3	Unit 3
Raw compost 3years	300 m^3	Unit 1

[a]New information was given about the stored compost at the landfill prior to the final determination of which material was going to be used in the full scale Biocover.

For division of the wood contents of the garden waste prior to composting, a facility exists at the landfill. The resulting product is however not cut as normal woodchips, but torn in order to create a large surface area (I/S FASAN, 2006a). The machine has 2

different settings and for shredding of garden waste the coarsest setting is used. The finer setting can be used for raw compost and screening residue before being used in biocovers. In figure 1 a flow diagram of the composting at Fakse landfill can be seen.
The garden waste compost is produced by shredding garden waste and composting it in madras's. The madras's are turned over 3 times during the 12 months period. This forms raw compost, which is screened and divided into screening residue and fine compost. Screening residue is reused in the composting process as structure material and bio stimulation.
The sewage sludge compost is made by mile composting of garden waste, straw and sewage sludge. During the initial mixing of the compost about 2% of screening residue is added. For the first 4 weeks the miles are mixed every week and for another 2-4 weeks every 2 weeks, so the total composting time is 6-8 weeks. Hereafter the compost is cooled for another four weeks. The sewage sludge compost is also screened and the screening residue is recycled.
The sewage sludge compost is screened coarser than the garden waste compost, so a material with a higher porosity will most likely be achieved.

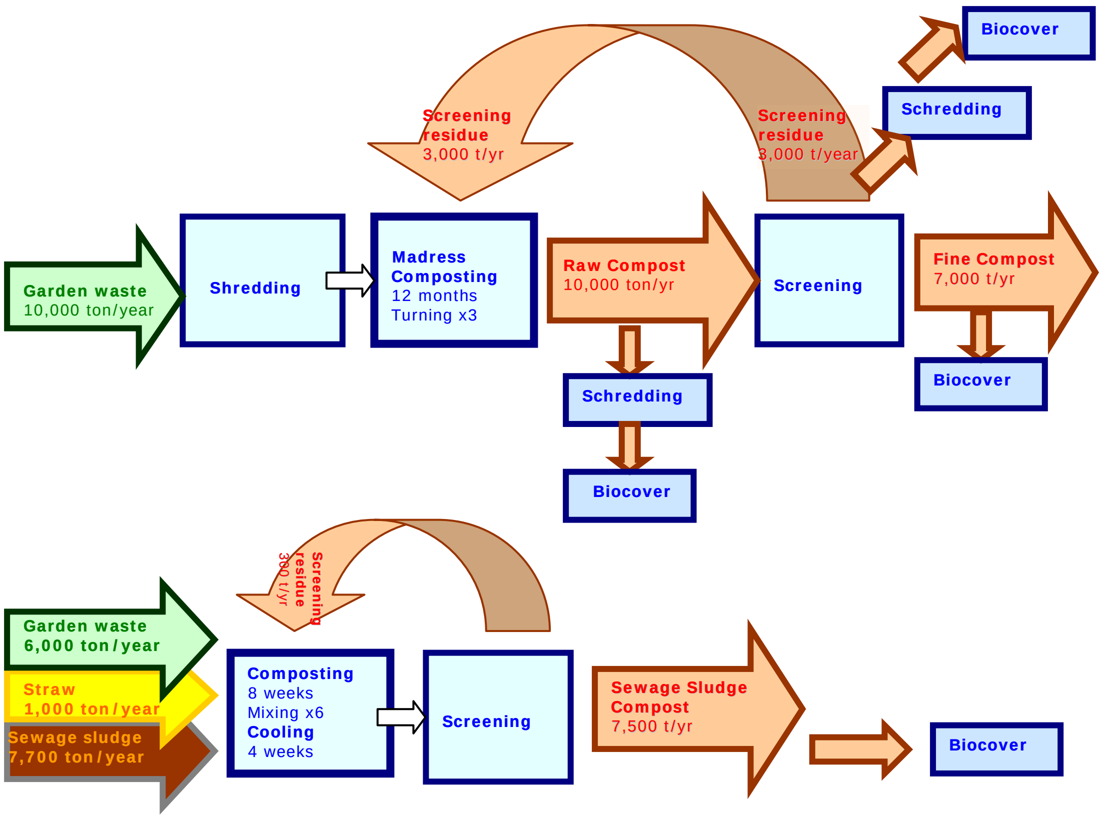

Figure 1.1: Flow chart for composting at Fakse Landfill. (I/S FASAN, 2006a; I/S FASAN, 2006b)

Inorganic materials

Primarily at Fladså Landfill, I/S FASAN receive some inhomogeneous loads of gravel mixed with other materials. However, since this is received as waste it cannot be used for final covering at the landfill. Therefore gravel and other inorganic materials must be bought. For construction of interim roads etc., I/S FASAN procure gravel and crushed stone from a nearby gravel pit. Material prices for selected materials procured from this site are seen in Table 1.2.

Table 1.2. Material prices from Lønggårdens gravel pit, Sorø and Lundby gravel pit, Bårse

Inorganic materials	Size	Density	Price	Price at 1300 m^2	Price at 5000 m^2
	mm	kg/m^3	DKK/tonne	DKK	DKK
Gravel					
Road gravel, partly crushed	0-16	1750	60[a]	27300[cd]	105000[d]
Stable gravel (DS/EN 13285)	0-32	1750	55[a]	25025[cd]	96250[d]
Gravel fill (DS/EN 13285)	0-32	1600	30[a]	12480[cd]	48000[d]
Sand					
Sandfill (unsorted) Lundby gravel pit		1600	56[b]	116480[e]	448000[e]
Washed sand 0/4	0-4	1600	87[c]	180960[e]	696000[e]
Washed sand 0/2	0-2	1600	123[c]	255840[e]	984000[e]
Washed sand 1/4	1 to 4	1500	153[c]	298350[e]	1147500[e]
Other materials					
Crushed stone (skærver)	32-50	1500	70[a]	27300[d]	105000[d]

[a](www.tjo.dk, 2006). Prices are exclusive VAT, raw material fee of 3 DKK/tonne and transport.
[b](Lundby gravel pit, 2006) Prices are inclusive transport from Lundby gravel pit, Bårse (20km)
[c](Thomas Juul Olsen, 2006) Prices are inclusive transport from Lønggårdens gravel pit, Sorø (57km)
[d]Calculated based on a gasdistribution layer of 20cm
[e]Calculated based on a biocover window layer of 100cm

In the project proposal a biocover window area of 1300 m^2 is estimated. If a gravel layer of 20 cm is needed this will result in a cost of 13,000 DKK to 27,000 DKK as seen in Table 1.2. If an area of 5,000 m^2 should be covered this cost will be approximately between 50,000 DKK and 100,000 DKK. If sand should be used as the main biocover window material, this cost will also be major. Using the cheapest sand the cost will be between 100,000 DKK and 500,000 DKK. As emissions has been found to be much higher than expected a biocover window of approximately 5,000 m^2 will most likely be needed and the inorganic materials will therefore represent a very significant cost especially compared to the compost materials, which are free and already present at the site so no transportation is needed.

Action 4.2 Characterization of materials and quick test determination of the methane oxidation capacity

From “Action 4.1: Overview of available materials” it can be seen in table 1 that there are 7 different materials/with different age at the site. It is chosen to test all of these materials in the quick test determination as it is not very laborious. The dependency of temperature and moisture is not done as it is found less relevant. If it is found to be of major interest later in the project it will be done on the finally chosen material. It is chosen to crush the raw compost and the sieving residue as it is believed to enhance methane oxidation because of increased surface area of the cover material. This can be done by the already available machinery at the sight.

Initially 7 materials are tested with different age and composition. Doing this and looking at the availability of the materials the aim is that the number of tested composts is narrowed down to 5 materials for further investigation in Action 4.3 Cover performance lab testing.

Materials and Methods

Materials

The preliminary test is a methane oxidation test and a respiration test. Furthermore the moisture content and the content of organic matter was determined. The later was determined by anignition loss test.

The compost materials which are chosen for quick test determination is:

- Fine compost of garden waste, 1-2 years **(FC)**
- Raw compost of garden waste, crushed, 1 year (**RC1)**
- Raw compost of garden waste, crushed, 3-4 years **(RC4)**
- Raw compost of garden waste, 7-9 years **(RC8)**
- Sewage sludge compost **(SC).**
- Sieving residue, crushed, 1 year **(SR1).**
- Sieving residue, crushed, 3 years **(SR3).**

In Table 2.12.1 the results of the water content and ignition loss can be seen.

Table 2.1: Water content, ignition loss and chemical properties for the 7 tested materials

	Water content[a]	*Ignition loss*[b]	*pH*[c]	*TOC*[d]	*N_{tot}*[e]	*NH_4-N*[f]	*NO_3-N*	*P*[g]	*SO_4*[h]	*Cu*[g]
	per 100g DM	per 100g DM		%DM	mg/kgDM	mg/ kgDM	mg/ kgDM	mg/ kgDM	mg/ kgDM	mg/ kgDM
FC	63.9±2.7	25.5±2.3	8.4	15	8480	735.5	91.3	1830	236	27
RC1	84.2±3.6	32.7±7.0	8.5	20	20950	4968.6	45.1	1590	60	25
RC4	72.2±1.4	29.3±3.4	8.4	16	10880	865.8	71.3	1710	-	37
RC8	45.2±1.4	22.5±3.0	7.7	20	9860	873.6	114.5	1760	-	46
SC	88.7±1.1	41.2±1.0	8,6	20	20950	4969	1.9	6360	924	43
SR1	72.8±1.1	58.6±2.1	8.4	20	12770	959.4	2.5	1760	32	29
SR3	89.5±3.2	41.1±3.0	8.5	16	10380	928.2	2.0	1830	102	25

[a]Weight loss after 24hours at 105°C [b]Weight loss after 2hours at 550°C. [c]Determined by commercial lab according to ISO 10390. [d]Determined according to ISO 10694. [e]Determined with a method based on DIN EN ISO 11261. [f]Determined according to DIN38406-E5-2. [g]Determined according to DIN 38406-E29. [h]Determined according to DIN EN ISO 17294-2 (E29)

Batch experiment

Methane oxidation experiment

The batch experiments are done by adding 20 g of moist material to 300 mL infusion bottles. The bottles are sealed with gastight rubber septas, 40mL of air is removed, 40 mL of methane is added and they are left over night to decrease the length of the lag phase. Next morning they are opened and ventilated for 20-30 minute, resealed and 140mL of air is removed from the bottles with a syringe and 40 mL of methane and 100 mL of oxygen is added. This results in concentration of app. 15 %vol CH_4 and 35 %vol O_2. All experiments are done in duplicate with 2 controls. Some materials had high oxygen demands and it was necessary to add oxygen during the experiment to avoid anaerobic conditions. Measured concentrations are in volume percent and recalculating is done by taking the pressure differences in the bottles into consideration. Methane oxidation rates are calculated by the linear part of the curve (zero order degradation, $r^2 \geq 0{,}98$ unless stated otherwise in table 2.3).

Oxygen consumption/respiration

The respiration tests are done in the same way as above but solely with atmospheric air. All experiments are done in duplicate and with 2 coarse sand controls.

Results and discussion

In Figure 2.1 results are seen for two selected materials, Raw Compost 4yrs (RC4) and Fine compost (FC). They are representative for most of the data obtained. For all bottles there is good agreement between duplicates and oxygen has been present under the entire experiment. In figure 2.1 it can be seen how methane and oxygen is used and carbon dioxide is being produced. The experiments are redone twice to see how the materials act when adapted to methane oxidation. For both materials (and all materials investigated) lag phases disappear, which is typical when pre-exposure has happened. For the RC4 it is seen that the methane oxidation rate is increasing for each time the experiment is redone and it reaches as the best material an average methane oxidation rate of 160.8 µgCH_4/g dry soil/h in the end of the experiment when redone for the second time, see Table 2.3.
The fine compost is an example of a material where methane oxidation rate decreased during the experiment. This can for instance be due to nutrient deficiency or EPS production (Hilger et al., 1999; De Visscher et al., 2001; Wilshusen et al., 2004a). In Table 2.3 it can be seen that the initial methane oxidation rate is 32 µgCH_4/gDM/h and

the second rate is 44.4 µgCH_4/gDM/h, which decreases to 26.8 µgCH_4/gDM/h. A decrease in the rate in the second repetition is seen for 3 of the materials (Table 2.3)

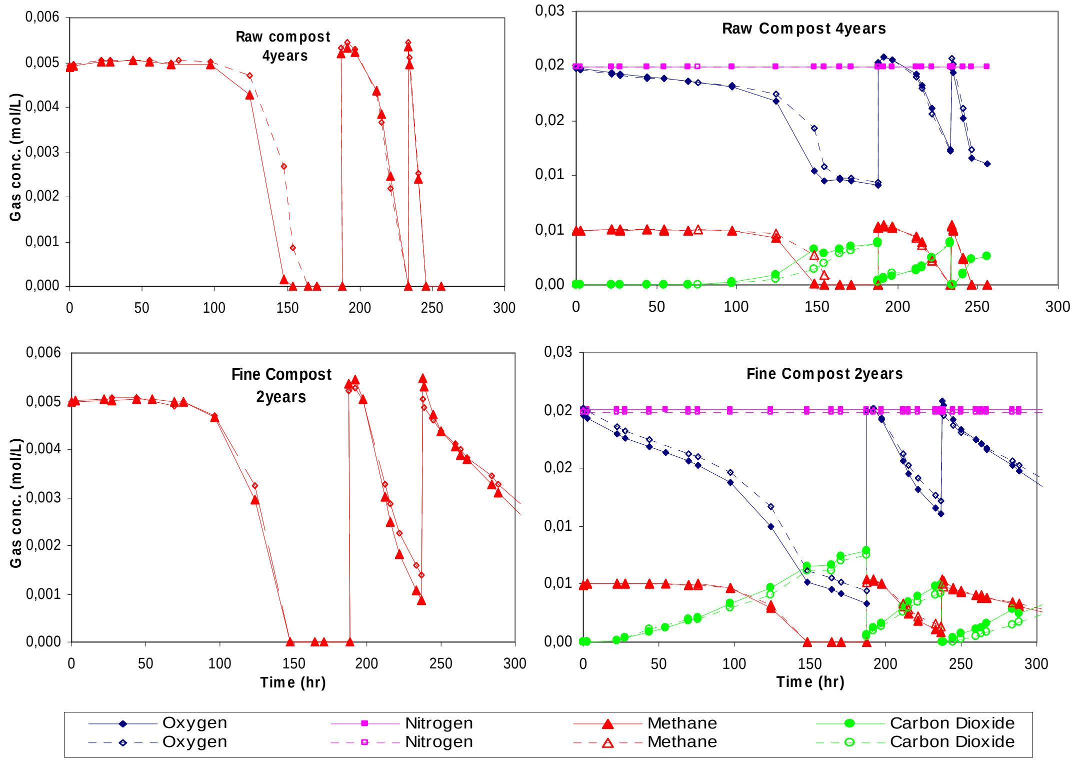

Figure 2.1: Gas concentration as a function of time for two selected materials; Raw Compost 4yrs and Fine Compost

In table 2.3 potential methane oxidation rates in the 3 subsequent experiments and the oxygen demand from separate experiments are seen. The data are plotted in Figure 2.2 to give a better overview. It can be seen that the oxygen demand is higher for younger and coarser composts. The RC1 has higher oxygen demand than the FC. The SC, which is produced in only 8 weeks with very active material, has a high oxygen demand and so does the 2 screening residues, the SR1 higher than the SR3.

Literature values of CH_4 oxidation rates of compost materials in batch incubation experiments are in the range of 5-480 µgCH_4/gDM/h (see table 2.2) depending on degree of pre-exposure and amount of organic matter. Mor et al., 2006 investigated a range of garden compost materials at different moisture and temperature regimes. A compost of garden waste produced by 6 months of passive aeration reached a methane oxidation rate of 47.4 µgCH_4/gDM/h after 20 days of pre-exposure (Mor et al. 2006), which is similar to the result achieved for the FC in the third run (44.4 µgCH_4/gDM/h) in the inherent study. In Mor e al. 2006 a compost, which was more efficient and had a lower oxygen demand produced by active aeration over 3 months reached a rate of 104.6 µgCH_4/gDM/h after 20 days (Mor et al. 2006). This is more in the range of what was achieved for the better composts in this study; 161 µgCH_4/gDM/h for RC4 and 133 µgCH_4/gDM/h for the SC. In respiration tests the oxygen demand of the better compost in Mor et al. 2006 was 8 µgO_2/gDM/h and 12 µgO_2/gDM/h for the less efficient compost. Respiration in Mor et al. 2006 is as a carbon dioxide production rate so glucose degradation is assumed in order to be able to compare the results. These are both very low oxygen demands compared to the inherent study. The general picture in Mor et al. 2006 was increasing methane oxidation rate over time, which is also comparable to this study.

Table 2.2: Methane oxidation rates in batch experiments from the literature with empathize on compost materials

Reference	*Material*	*Pre-exposing*	*Maxs. rate*	*Start konc.*	*Tem-pera-ture*	*Porosity/ grain size*	*Org. matter*	*Water con-tent*
			μg/t gDM	Vol%	°C		%DM	%DM
Figueroa 1993	Mould	1-2uger lab[e]	32	10	20		4,4[c]	9-18
	Humic soil	1-2uger lab	86	10	20		7,1[c]	17-33
	Compost of org. matter	1-2uger lab	128	10	20		32[c]	68-135
Kightley et al., 1995	Coarse sand	6month, lab[e]	26	5	20			
	Coarse sand with sewage sludge	6month lab[e]	19					
Borjesson et al., 1998	Mineral soil jord, mostly sand	1år felt[f]	9	0,6		0,35	3,2	
	Old sewage sludge (3-4years)	3-4year field[f]	173	5		0,69 15%c.s.[b] 12%f.s.[b]	25	28
	Fresh sewage sludge	1år field[f]	5	0,6		0,79	38	
De Visscher et al., 1999	Agricultural soil	Yes	V_{max}= 26	3	22			15
Gebert et al., 2003	Expanded clay pellets	No	11		30	4-8mm		
Streese et al, 2003	Compost of garden waste[g]	Yes	143[d]	2,5[a]	20-30	Fine	28,2	48,9
	Mixture of fine compost of garden waste, peat and wood fibers[h]	Yes	85[d]	2,5[a]	20-30	Coarse	52,1	
Wilshusen et al., 2004b	Leafs composted with zoo manure	6month lab	V_{max}= 480	10	22	Fine	46	123
	Compost of woodchips	6month lab	V_{max}= 124	10	22	Coarse	34	123
	Compost of municipal solid waste	6month lab	V_{max}= 249	10	22	Coarse	49	123
Mor et al., 2006	Garden waste compost, pass. aer.[i]	20days, lab	47,4	5	22		52,1	58,5
	Garden waste compost, int. aer.[i]	20days, lab	104,6	5	22		31,1	49,5

[a] Constant inlet concentration in biofilter [b] Short for coarse sand and fine sand. [c] Calculated assuming that ignition loss is two times TOC (Total Organic Carbon). [d]Calculated assuming methane oxidation in the entire volume of the filter [e]Preexposed in the lab [f]Preexposed in the field [g]TKN=7,75g/kg, $[NH_4^+]$ =732mg/kg, $[NO_3]$=200mg/kg. [h] TKN=7,37g/kg, $[NH_4^+]$ =881mg/kg, $[NO_3]$=166mg/kg. [i] Passively and intensively aerated under production for 6 and 3 months respectively

Table 2.3: Potential methane oxidation rates in the 3 subsequent experiments and oxygen demand from separate experiments for the 7 materials

	Methane	***Methane 1***	***Methane 2***	***Oxygen Demand***[a]
	μg CH_4/g dry soil/h	μg CH_4/g dry soil/h	μg CH_4/g dry soil/h	μg O_2/g dry soil/h
Fine Compost 2yrs	46.0 ±3.0	26.8 ±13.2	44.4 ±6.3	34.8 ±3.1
Raw Compost 1yr	10.6 ±0.2	13.2 ±1.1	24.7 ±4.7	62.4 ±1.2
Raw Compost 4yrs	53.4 ±14.9 [a]	74.9 ±1.3	160.8 ±2.4	3.8 ±2.1
Raw Compost 8yrs	3.2 ±0.2	4.8 ±0.5[b]	7.4 ±1.2	6.1 ±0.2
Sewage Sludge Compost	18.8 ±0.8[c]	85,7 ±2.0	141.5 ±44,6	122.4 ±1.3
Screening Residue 1yr	18.5 ±3.0[d]	11.4 ±2.6	11.2 ±1.5	95.2 ±9.4
Screening Residue 3yrs	12.3 ±2.2[e]	41.3 ±28.8[f]	35.6 ±18.9[g]	66.1 ±12.8

[a]Oxygen demand is measured in separate experiments and is therefore independent of methane oxidation rate.
[a] $r^2 \geq 0.92$, [b] $r^2 \geq 0.979$, [c]$r^2 \geq 0.859$, [d]$r^2 \geq 0.941$, [e]$r^2 \geq 0.955$, [f]$r^2 \geq 0.962$, [g]$r^2 \geq 0.947$.

In Figure 2.2 an overview is given of the three methane oxidation rates for the seven

materials and the fourth and hatched column is the oxygen demand of each material in separate experiments. Obviously high methane oxidation rates are required and generally low oxygen demand is sought as the oxygen demand of the compost competes with the oxygen demand of the methane oxidation. Though a material with high gas permeability can compensate for this, as for instance is the case with the screening residue.
Generally care has to be taken when results from batch experiments are analysed. There are two major parameters that these results do not take into account

- Long term performance of the biocover material
- Gas permeability of the material

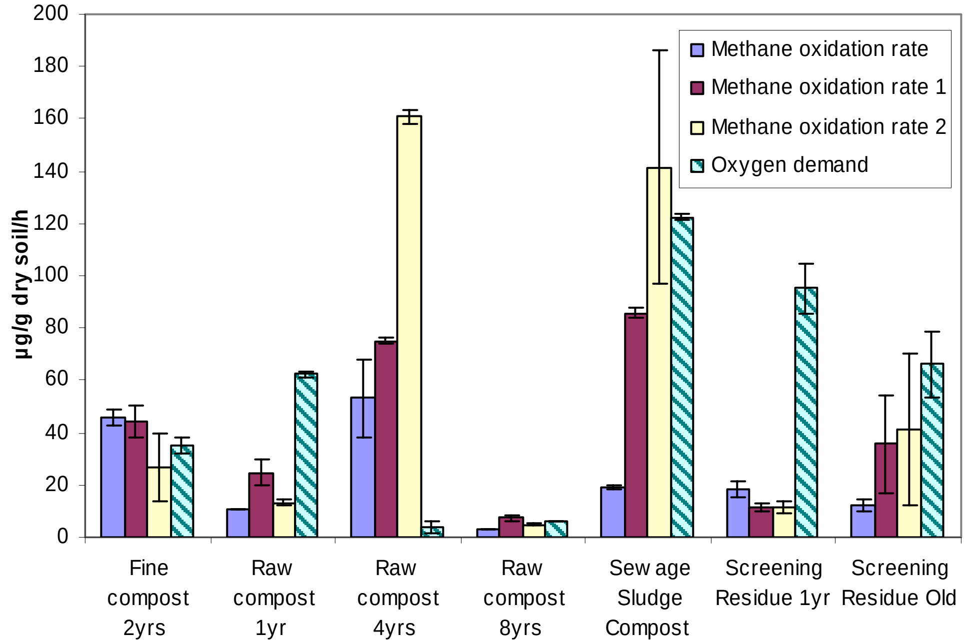

Figure 2.2: Methane oxidation rates for the 3 subsequent experiments and oxygen demand from separate experiments for all 7 materials. Error bars correspond to one standard deviation.

High rates are seen for the raw compost 4yrs and the sewage sludge compost, which are therefore the materials with the most promising results.

Table 2.4: Methane production of the seven materials

	Methane production	
	µgCH_4/gDM/h	
Fine Compost 2years	0.0	±0.0
Raw compost 1year	1.5	±0.2
Raw compost 4year	0.0	±0.0
Raw compost 8year	0.0	±0.0
Sewage Sludge Compost	2.9	±0.2
Screening Residue 1year	5.2	±1.0
Screening Residue Old	1.3	±0.5

In table 2.4 potentials for methane production can be seen. If anaerobic conditions is achieved in the bottom of biofilter consisting of very organic materials methane can be produced. If the methane is degraded higher in the biofilter it is not a problem but it is something that should be followed. The methane production follows the same pattern as the oxygen demand. The younger and/or coarser the material the higher the methane production

Choice of materials for "Action 4.3: Cover Performance Lab Testing"

Choosing 5 materials for the lab testing different parameters should be taken into consideration.

- Potential methane oxidation rate
- Oxygen demand
- Porosity and gas permeability
- Availability
- Price

In order to assess the availability of the materials it is needed to do an estimate of the needed volume for the biocover. In Biocover task 2: Initial Characterization of Fakse Landfill there are estimated LFG production rates to range from 3-8 g $CH_4/m^2/d$ in the capped part and 8-16 g $CH_4/m^2/d$ in the uncapped part of section I. Assuming no or very low methane oxidation in the clayey top cover a load of 10 g $CH_4/m^2/d$ is assumed. Section I is located at the eastern side of the site and covers an area of 12.1 hectars of which 10.3 hectars are used (). With a load of 10 g $CH_4/m^2/d$ and a rate of 200 g $CH_4/m^2/d$ an area of about **5,000 m^2** should be covered with window. The thickness of the cover should be about 1m as methane oxidation can take place in a depth of 1m especially when having a coarse material where penetration of atmospheric air (oxygen) is deep. Therefore about **5,000 m^3** of the material should be present.

Porosity, structure and stability of some of the materials can be improved by adding sand. A pure compost material will typically be compacted due to settlement and degraded over time and gas permeability will be reduced. The FC from Fakse will be compacted/degraded by app. 10cm in a year (I/S FASAN, 2006) and using this material pure, a high degree of maintenance of the windows will be needed. Also woodchips can be added as a structure material but as it is organic its durability is lower than the one of sand. Though as the needed window area in the project has increased significantly from the plan (1300 to 5000m^2) the cost of buying and transporting sand to the site is not within the budget frame. The cost of using the sand in the windows would be around 50,000 euro and it will only be a possible solution if the materials are available at the site. It is therefore chosen to test the materials without adding a structure material, thus this will increase the risk of methane oxidation being limited by the oxygen demand of the compost it self and the risk of clogging due to EPS production (Hilger et al., 1999; Wilshusen et al, 2004a). Porosity and gas permeability is not yet measured but just by visual inspection there is a significant difference between the materials. Especially for materials with high oxygen demands a high porosity is needed.

The RC4 (160.8 $\mu gCH_4/gDM/h$) and SC (141.5 $\mu gCH_4/gDM/h$) are obvious choices as they show very good results in the initial screening. The RC4 is limited by its availability, but shows a great potential. Furthermore the results for the RC4 give an idea of the efficiency of RC1 after 4years of performance. Also for the screening residue better results are seen for the older product (35.6 $\mu gCH_4/gDM/h$) than the fresher one (11.2 $\mu gCH_4/gDM/h$). As only one column is left it is chosen to test the new screening residue as the other one does not have any practical interest in this project because of the limited availability. Mixing the two was considered but this was discarded as it involves a significant cost. It is assumed that the high gas permeability compensates for the high oxygen demand, though woodchips can be added to decrease the oxygen demand and increase structure. This is also a solution if availability is revealed to be an issue.

In Table 2.5 it is tried to do a system matrix for choosing the materials for further investigation. The 5 parameters are listed together with the 7 materials and there are given plusses for performance in the five categories. Four plusses are very good and one plus is very poor. In the last column there total score is seen and it is stated whether the materials are used for further investigation.

Table 2.5: Matrix for choosing materials for Task 4.3: Cover Performance Lab Test

Material	*CH_4 ox.*	*O_2 demand*	*Porosity and gas permeability*	*Avail-ability*	*Price*	*Score/ Column?*
FC	+++	+++	+	++++	+++	14/Yes
RC1	++	++	++	++++	++++	14/Yes
RC4	++++	++++	++	+	++++	15/Yes
RC8	+	++++	++	+	++++	12/No
SC	++++	+	+	++++	+++	13/Yes
SR1	++	+	++++	+++	++++	14/Yes
SR3	+++	++	+++	+	++++	13/No

++++ very good for methane oxidation, +++, good for methane oxidation, ++ poor for methane oxidation, + very poor for methane oxidation and so on for all categories.

The following 5 materials were chosen for further testing in column experiments.

- Fine Compost **(FC)**
- Sewage Sludge Compost **(SC)**
- Raw compost 4yrs **(RC4)**
- Raw compost 1yr **(RC1)**
- Screening Residue 1yr **(SR1)**

Action 4.3 Cover performance lab testing

The five types of cover materials that were chosen in Action 4.2 were tested in a laboratory column setup. By simulating the combined advective-diffusive transport and attenuation that takes place in a LFG affected compost biocover, the overall degradation rates of methane can be estimated. The column experiment was started at January 30, 2007. The column experiment has been run for approximately 4 months (111 days)

Materials and Methods

Test materials

The five tested types of cover material were:

- Fine Compost
- Raw Compost 1 year
- Raw Compost 4 year
- Sewage Sludge Compost
- Screening Residue

The control column was filled with gravel. The different compost materials were dry when received, and therefore sprayed with water to reach the natural moisture content (listed in Table 2.1). Larger parts (> 5 cm) of stones and twigs were removed from the materials and a good part of each material was kept for water content analysis and other analysis.

Experimental Column Setup

An illustration of the experimental setup is shown in Figure 3.1 and close-up pictures of each column are given in appendix A. In appendix B a table with the column data is given.

The column setup consisted of 6 PVC columns closed in both ends with PVC caps fitted with rubber O-rings. The columns were 1 meter high, with an inner diameter of 0.2 meter. Each column had a gas inlet in the bottom and in the top. In the bottom a mix of 50 vol% CH_4 and 50 vol% CO_2 was pumped in at a constant rate (13-15 ml/min), simulating landfill gas. The gas mixture was obtained from Hede-Nielsen/Air Liquide, Denmark. In the top of the columns an inlet provided each column with atmospheric air with a flow rate of approximately 60 ml/min for each column. The pumps used in the experiment were gastight piston pumps (FMI lab pumps model QG), both in top and bottom of the columns. The columns also had an outlet port in the column tops. The columns had 19 gas sampling ports placed with a 5 cm interval down each column. The sampling ports were numbered from 1 in the bottom to 19 in the top.

In the bottom a fine-meshed net (3 mm) was placed to avoid clogging of the gas inlet. On top of the net a layer of 3 cm fine gravel was placed to ensure a homogenous distribution of the gas in the column. The compost material was then placed by adding 5 cm at the time, then pound it lightly with a rubber ended metal stick. To avoid layering, the top was gently loosened before the next portion of compost was added. The columns were filled with compost material in this way up to approximately 8 cm from the top cap, between the two highest sampling points (port 19 and 18).

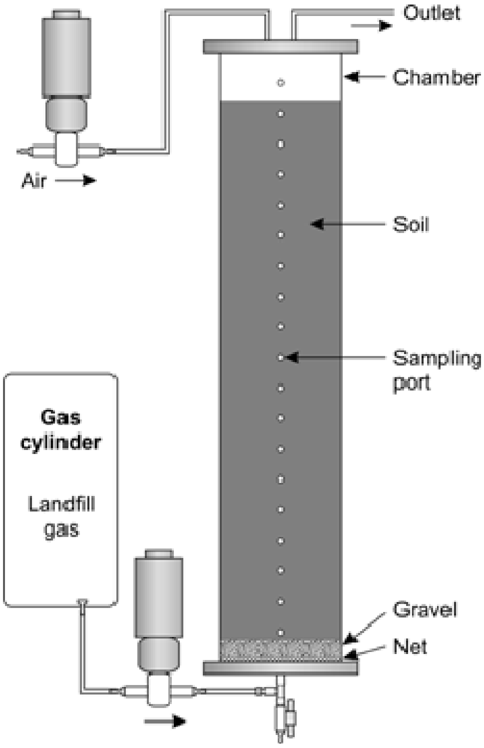

Figure 3.1: The six columns in the lab. The columns were wrapped in paper to protect the compost materials from light.

Flow rate measurements

The inflow rates to the bottom of the columns were measured using 2 different methods. This was done to investigate the uncertainties and the impact of the given porosity of the column material on the flow rate. One method (A) was to let a drop of water in to the tube connecting the gas cylinder with the columns. This was done both before and after the pump. Knowing the tube diameter and the time for a drop to travel a given length of the tube, the flow could be estimated. The second method (B) was to use a common flow meter where bobbles of water travel in a known volume while the time is measured. Method B could only be used in the tube after the pump (just before the inlet to the column). It was found that the flows obtained with method A were all lower than the flows measured with method B, except for the control column. The high B flows were expected, since the tube was not connected to the columns during the B measurements, letting the gas travel without resistance from the columns.

The inflow of atmospheric air in the top was set to 100 ml/min until day 43. Hereafter the inflow was reduced to 60 ml/min for all columns because of low methane concentrations in the top sampling ports. The methane concentrations observed before day 43 were around or below the detection limit of the MicroGC, resulting in high uncertainties. The flow rates in and out of the columns have been measured several times throughout the experiment period and an average of the measurements are used in the calculations.

Table 3.1: Experimental data for the six columns. Water content, ignition loss, bulk density, gasfilled porosity and gaspermeability for the 5 tested materials packed in the columns

	Water content[a]	*Ignition loss*[b]	*Bulk Density*	*Porosity*[c]	*Gas permea-bility*[d]	*Average inflow rate, bottom*	*CH_4 load*
	per 100g DM	per 100g DM	kg/m^3	Gasfilled/ total	m^2	ml/min	g/m^2/day
Fine compost	76.2±4.3	24.9±2.5	505.4	0.48/ 0.86	3.55E-12	13.1 ± 1.7	196
Raw compost 1yr	97.1±5.5	39.8±7.4	356.1	0.44/ 0.79	3.31E-12	12.9 ± 1.1	193
Raw compost 4yrs	71.9±1.5	31.6±1.2	486.61	0..40/ 0.75	2.98E-12	13.6 ± 0.8	204
Sewage Sludge Compost	86.86±5.6	36.5±2.8	330.6	0.40/ 0.68	2.96E-12	13.5 ± 0.8	202
Screening Residue 1yr	110.6±7.1	58.8±3.2	286.71	0.52/ 0.83	3.85E-12	13.7 ± 0.8	206
Control	-	-	-	-	-	14.7 ± 1.6	220

[a] Weight loss after 24hours at 105°C. [b] Weight loss after 2hours at 550°C. [c] Determined from the retention time by trace gas experiments. [d] Determined from one corresponding measurement of pressure drop and flow.

Sampling Procedure

The sampling program consisted of profile sampling and outlet sampling. Profile sampling was done by sampling in 15 of the 19 sampling ports (ports 1, 3, 5, 7, 9 – 19) to get samples from the whole column length. This was done approximately once a week. The outlet sampling was done in the top sampling port (port 19) and was carried out approximately 2 times a week (including the profile sampling). The sampling programme is given in appendix C.

The gas was sampled with a 5 ml plastic syringe and transferred to 5 ml evacuated glass vials (Exetainer™ type 819W from Labco). Also the inlet gas (50 vol% CH_4 and 50 vol% CO_2) and the laboratory air were sampled to measure the exact amount of CH_4, CO_2 and O_2 in the inlet.

Measured inlet concentrations to the columns are given in Table 3.2. The inlet concentration of the artificial landfill gas was measured for every new gas cylinder that was used during the experiment time and the average concentrations given in the table was used for the calculations of oxidation rates etc. The concentrations of methane, carbon dioxide and oxygen in the atmospheric air in the cupboard were measured 3 times during the experiment time, and the average was used in the calculations.

Table 3.2: Measured inlet concentrations to the columns from the 50/50% mix of methane and carbon dioxide in the bottom and atmospheric air in the top.

	Inlet concentration, bottom	*Inlet concentration, top*
	Vol%	Vol%
Methane	49 ± 3	0.0 ± 0
Carbon dioxide	50 ± 3	0.0 ± 0
Oxygen	0.92 ± 1	22 ± 1

Gas analysis

The vials were analysed for methane, oxygen, nitrogen and carbon dioxide on a Chrompack Micro-GC CP-2002 in the lab. The gas chromatograph had a thermal conductivity detector and two Chrompack columns. Oxygen, nitrogen and methane (high concentrations) were measured on a 4 meter Molsieve 5A column and carbon dioxide and methane (low concentrations) were measured on a 10 meters long Poraplot Q column.

The column temperature was 40°C and the carrier gas was helium. The gas standards were produced by MicroLab, Aarhus, Denmark. The computer software used for the identification of the compounds was Maestro II, Chrompack 1995.

The vials were all analysed within one week of the sampling time.

Calculation of methane oxidation capacity and efficiency

The methane oxidation capacity was calculated for each column as g CH_4 /m^2/day. The calculations were done on basis of the inlet concentration ($C_{CH4,\ inlet}$) of methane to the columns (~ 49%) and the concentration observed in the top sampling port in the column ($C_{CH4,\ outlet}$) related to the inflow and outflow rates (Q) to the column and the column area. The mass balance for the methane oxidation rate in the columns (r_{CH4}) can be written as:

$$capacity_{CH4} = C_{CH4,\ inlet} * Q_{inlet} - C_{CH4,\ outlet} * Q_{outlet}$$

The methane oxidation efficiency (%) was calculated as the amount of removed methane in the top of the column compared to the amount of methane pumped into the column:

$$efficiency_{CH4} = (M_{CH4,\ inlet} - M_{CH4,\ outlet})/ M_{CH4,\ inlet}*100\%$$

Results and Discussion

Methane oxidation rates

Figure 3.2 shows the methane efficiencies for the 5 cover materials and the control throughout the test period. It should be noticed that the timescale starts from day 10 because of uncertain data the first 10 days. Table 3.3 gives an overview of the maximum and average methane oxidation rates and the methane oxidation rates in the end of the experiment for the 5 materials.
In the following a more detailed description of the observed oxidation pattern of the different compost materials are provided.

Fine compost

The methane oxidation rates have been increasing in the period until day 35 (196 g/m^2/day) and hereafter decreasing to a level of around 35% (~75 g/m^2/day). But in the last period a tendency to an increase is seen.

Raw compost 1 year

The oxidation rates have been rather stable after the first 10 days of the experiment, with maximum oxidation rate of 45% (79 g/m^2/day) on day 23. Hereafter the oxidation rates have been decreasing to reach a more stable level around 30% (~41 g/m^2/day).

Raw compost 4 year

The methane oxidation rates have in the period of day 11 to 101 overall been decreasing from 75% to around 45% (~87 g/m^2/day).

Sewage sludge compost

The methane oxidation rates have been increasing until day 41 (98% ~195 g/m^2/day) and hereafter decreasing to a level of around 50%.

Screening residue

The methane oxidation has generally been increasing from around 10% to around 35% (~70 g/m^2/day) from day 10 to 101.

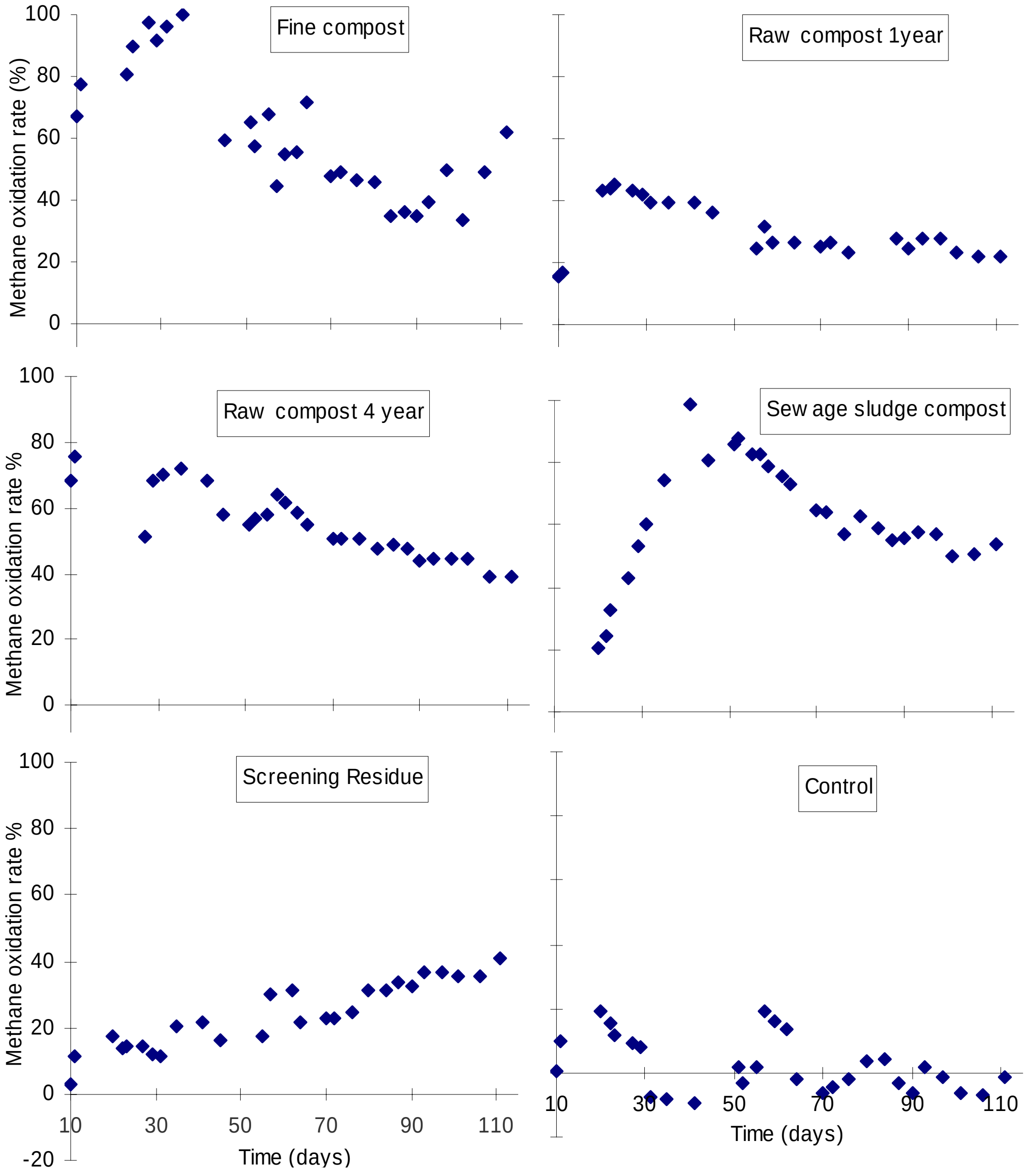

Figure 3.2. Methane oxidation rates from day 10 to day 111 for the 5 materials and the control. The rates are given in %.

Table 3.3: The maximum and average methane oxidation rates and the methane oxidation rates in the end of the test period (day 111) for the 5 materials and the control.

Column	*Maximum methane oxidation rate observed*			*Average methane oxidation rate*		*Methane oxidation rate observed on day 111*	
	Day	$g/m^2/day$	%	$g/m^2/day$	%	$g/m^2/day$	%
Fine compost	35	196	100	120 ± 40	61 ± 1	122	62
Raw compost 1yr	23	79	45	52 ± 16	30 ± 9	38	22
Raw compost 4yrs	11	147	75	108 ± 20	55 ± 10	76	39
Sewage Sludge Compost	41	195	98	112 ± 56	56 ± 28	107	54
Screening Residue 1yr	97	72	37	45 ±21	23 ± 11	81	41
Control	57	39	19	2 ± 15	1 ± 8	-2.6	-1.3

In table 3.3 it can be seen that the average methane oxidation rates are as follows. FC 120 $g/m^2/day$, SC 112 $g/m^2/day$, RC4 108 $g/m^2/day$, RC1 52 $g/m^2/day$, SR1 45 $g/m^2/day$. The 3 best materials have rather similar rates, but looking at the graphs the development over time is most promising for the fine compost. This is also seen by the fact that it clearly has the highest methane oxidation rate in the end of the experiment (122 $g/m^2/day$). But other parameters have to be taken into account when choosing the material for the biocover windows at Fakse landfill.

Generally an initial increase in oxidation activity during the first 30-40 days was seen probably due to adaptation, reaching max around day 40 and then a slightly decrease is observed. This phenomenon is very well known in the literature. (Kightley et al., 1995; Hilger et al., 2000; Wilshusen et al., 2004b). In the latter reference a maximum oxidation rate of 63% was achieved for an unsieved compost of woodchips after approximately 100days of performance landing on app. 25% after 200days. A maximum rate of 100% was achieved for a garden waste composted with manure, landing on a constant rate of 25%, which resembles the results obtained for the Fine compost and the Sewage sludge compost in the inherent study. The increase and decrease is less pronounced for the screening residue, which generally shows a small increase in oxidation efficiency throughout the period. So it can be assumed that it has no yet reached its maximum capacity.

It can be seen from Figure 3.2 that most of the materials have not reached a stable level of methane oxidation. The raw compost 4years and the sewage sludge compost are likely to keep decreasing in oxidation efficiency. Though there seem to be a slight tendency that another increase in methane oxidation rates is seen for the fine compost, which has also been reported in the literature previously. (De Visscher et al., 1999; De Visscher & Cleemput, 2003;Wilshusen et al., 2004a) Raw compost 1 yr and screening residue can be considered to have reached more stable oxidation levels though a further increase would be expected for the screening residue.
De Visscher et al. 1999 worked with similar loads of methane (224 $g/m^2/day$) and reached a maximum rate of 176 $g/m^2/day$ and a constant rate of 80 $g/m^2/day$ for an agricultural soil amended with beat root leaves, which is quite similar with the results obtained in this study.

Gas profiles

Figure 3.3 illustrate the gas profiles in the initial period (day 11 – first row) and in the stable period (day 72 – second row). The gas profiles change in more ways from the initial phase to the end of the experiment. The oxygen levels through the columns at day 11 are generally higher and reach further down in the columns than at day 72. There are signs of methane oxidation at day 11, but the oxidation at this day generally takes place in a lower part of the columns than at day 72, where CO_2 generally is produced much higher in the column. The CO_2 and CH_4 profiles in the control column are almost identical, indicating little or no methane oxidation.

The decrease in oxygen level can be explained by the increase in methane oxidation, but may also indicate clogging of the column due to formation of ExoPolySaccharides (EPS)[1]. This is found to explain the behavior of the sewage sludge compost, which was

[1] EPS is long-chained glucose molecules made by bacteria as methanotrophs. EPS is observed in dynamic flow experiments with high inlet methane fluxes {Pedersen, 2004 10 /id}.

observed to develop a red-brown color in the column and a typical smell indicating anoxic conditions in the lower parts of the column, see photo in appendix B. The N_2 levels at day 72 are also very low in the bottom of the columns, only the screening residue show N_2 concentrations above zero in the lowest sampling port. This can be explained by the relatively high porosity and gas permeability of this material (see Table 3.1).

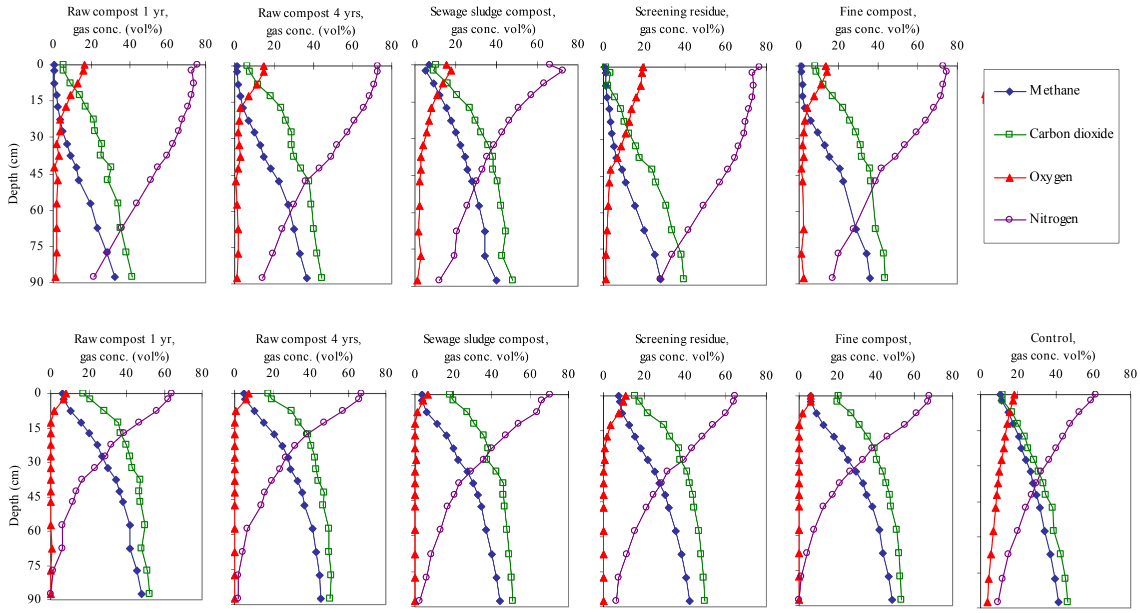

Figure 3.3. Gas profiles for the 5 materials and the control from day 11 (first row) and day 72 (second row).

The CH_4/CO_2 ratio can be used as an indicator for methane oxidation as methane is removed carbon dioxide is produced. So the lower a CH_4/CO_2 ratio the more methane oxidation is present. The movement of the ratio profile through the period is illustrated in Figure 3.4 below for RC4. The ratio is highest in the beginning of the experiment, indicating no methane oxidation. The ratio decrease until around day 23 indicating that more CO_2 is produced due to methanotrophic bacteria build up in the column causing increased methane oxidation. There is an increase in the ratio until around day 57 where the ratio stabilizes around 0.3 in the top and 0.9 in the bottom of the column. The same pattern is seen for the 4 other materials, though the SR keeps increasing after Day 57 to Day 101 so as is also seen in Figure 3.2 the methane oxidation is most likely to keep increasing for this material after the experiment has ended.

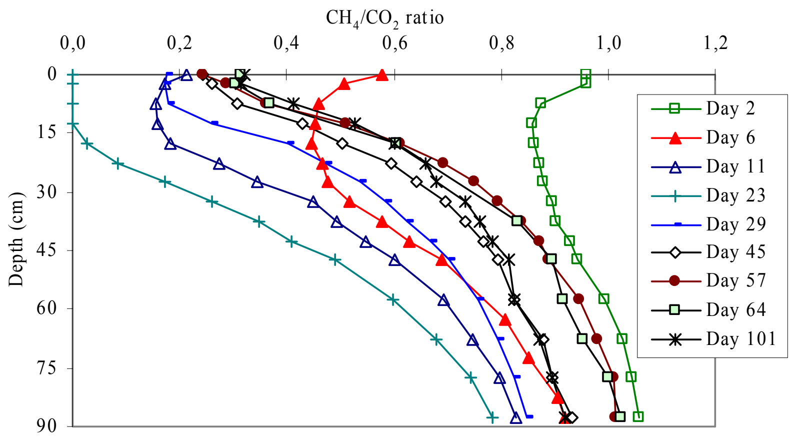

Figure 3.4: Ratio of CH_4 and CO_2 in the column with RC4.

Full scale at Fakse Landfill

Total methane emission from the Fakse landfill has been measured to 740 kg/day for section 1 {Scheutz, 2007 8 /id} which in a 5000 m^2 biocover {Fredenslund, 2007 9 /id} gives an inlet flux of 148 g/m^2/day. This inlet flux is lower than the one used in the laboratory columns (app. 200 g/m^2/day). Comparing the inlet in the field directly to the methane oxidation capacities found in the laboratory for fine compost (120 g/m^2/day) the goal of 90% is nearly achieved (81%). Using the results for RC4 (108 g/m^2/day) an efficiency of 73% is reached, but a lower inlet will most likely cause lower methane oxidation rates. Furthermore the results in the laboratory are probably done under favorable conditions compared to the field. The experiments are done in room temperature and very homogeneous gas flows are secured due to the relative small area of the column set-up. Though the opposite can be the case as the clogging with EPS could be lower in the field due to varying load and percolating precipitation. Furthermore rather high temperatures are seen in the methane oxidation zones in field experiments as heat is produced when methane is oxidized.

It would almost certainly give a better estimate of the efficiency if the percent rates are used. The rates are 61% and 55% for FC and RC1 respectively, which is quite far from the goal of 90%, though lower inlet flow can result in higher per cent oxidation (Scheutz & Kjeldsen 2003).

Choice of material for the full scale biocover

The material for the full scale biocover windows at Fakse Landfill should be determined. This should be done both by looking at the laboratory results and more practical aspects. Previously in the initial testing porosity, gas permeability, availability and price has been used as important parameters. As the amount of material needed has increased significantly the more practical aspects has more weight (price and availability).

The highest average methane oxidation rate in the column experiment is reached by the fine compost (120 ± 40 g/day/m^2). Though the stability of these results can be put into question as the rates are decreasing over time. RC4, SC and FC reaches similar average methane oxidation rates over the 4-month period and availability and cost is evaluated for the three materials. It is obvious that the methane oxidation rate of the SC is decreasing over time therefore it will not be a good choice considering the biocover windows should function for at least a year and preferably a lot longer without major maintenance. Furthermore, it is a compost which due to its high nutrient content should be used in agriculture as a fertilizer. The RC4 is the one of the three materials that shows the most stable methane oxidation of the three and it is therefore a good choice for the biocover windows. Furthermore, it is the cheapest available material as it does not need screening or shredding prior to use in the biocover windows. As the amount of material has increased from the project application the cost per m^3 of material is getting more significant. Also the availability of this compost has increased since the initial screening. New information was given in April 2007 that a huge pile of 4,000 m^3 raw compost and screening residue >5years was placed at unit 6. And also additional piles of raw compost 2 and 3 years were reported; 800 m^3 and 300 m^3 respectively. Still app. 1000m^3 of biocover material is needed so another material has to be chosen. It is wanted to use an older material as they seem to have more stable methane oxidation rates. It can be seen that the results for the SR1 from the column experiments seem very stable in the sense that the methane oxidation rate has increased over the entire 4-month period. Therefore this material will supposedly have a good efficiency over a longer period of time (>1-year.) And with its slightly higher porosity and gas permeability it is also more realistic that good influx of methane and oxygen is secured. Therefore another glance is done at the Screening Residue 3 years, which is not tested in the column experiments but only in batch. SR3 reaches a methane oxidation rate in the batch experiments, which is higher (36µg/gDM/h) than the one for the SR1 (11 µg/gDM/h) so this material will be expected to have a higher offset in the column experiment than the SR1.

Furthermore, the landfill operator is very happy to be able to use some of their deposits of old compost lying around, which they have not been able to sell and therefore it has no commercial value. Though when using the old composts it has to be taken into account that they should not be too old as the RC8 reached very low methane oxidation rates in the batch experiments (7.4 µg/gDM/h) at a maximum. Due to the above the biocover windows are primarily filled with Raw Compost 4years and Screening Residue 3years.

Conclusion

The objective of the study described in this report was to choose a material for the use in the full scale biocover windows at Faxe Landfill and to get an idea of the expected efficiency in the field by doing lab testing. The central parameter was methane oxidation efficiency over time but availability and costs were also considered when choosing the material. Three materials had similar results in terms of methane oxidation rates in the lab testing: Fine Compost 120g/m^2/day, Sewage Sludge Compost 112 g/m^2/day, and Raw Compost 4years 108 g/m^2/day. The cheapest and most available material of the 3 was chosen. This was clearly the Raw Compost 4years as it had no other use and did not need preparation prior to the use in the biocover windows. The Fine Compost needs screening and the Sewage Sludge Compost can be used in agriculture. The lab testing made it possible to look at practical aspects as methane oxidation was not found to be significantly different for the 3 materials above. Furthermore practical aspects also did reveal to be more important as the biocover window area increased from 1300m^2 to 5000m^2.

Furthermore, it was found that due to the results obtained in the laboratory in Task 4 and the higher emissions from the landfill found in Task 3 it is very unlikely that the proposed removal rate of 90% will be reached. Probably a removal rate of app. 50% is more likely.

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1 Appendix A – Pictures of the columns

Pictures of the 5 cover materials and the control in the column setup (day 106).

Raw Compost 1 year | Raw compost 4 year | Sewage Sludge Compost

Screening Residue | Fine Compost | Control

2 Appendix B – Column data

The data shown in the table are the data used for the calculations of methane oxidation rates for the columns.

Length	1	m
Effective length*	0,9	m
Inner diameter	0.2	m
Volume	0.126	m^3
Effective volume*	0,113	m^3
Area	0.0314	m^2
Lab temperature	25	°C
Atmospheric pressure	1	atm

* The length and volume of the material-filled column

3 Appendix C – Sampling programme

Sampling programme - column experiment			
Week	**Date**	**Day nr.**	**Remarks**
5	30-01-2007	0	Experiment start - gas bottle 1
	31-01-2007	1	Profiles
	01-02-2007	2	Profiles
6	05-02-2007	6	Profiles
	07-02-2007	8	Outlet samples
	08-02-2007	9	Profiles
	09-02-2007	10	Outlet samples
	10-02-2007	11	Profiles
7	16-02-2007	17	Gas bottle 2
8	19-02-2007	20	Profiles
	21-02-2007	22	Outlet samples
	22-02-2007	23	Profiles
9	26-02-2007	27	Outlet samples
	28-02-2007	29	Profiles
	02-03-2007	31	Outlet samples
10	06-03-2007	35	Outlet samples
	07-03-2007	36	Gas bottle 3
	08-03-2007	37	Profiles. Inlet of gas not OK
	09-03-2007	38	K5 pump down
11	12-03-2007	41	Outlet samples
	13-03-2007	42	K4 pump down
	14-03-2007	43	Inflow in top => 60 ml/min. All inflow pumps OK
	16-03-2007	45	Profiles
12	19-03-2007	48	Outlet samples.
	22-03-2007	51	Profiles
	23-03-2007	52	Outlet samples. Gas bottle 4
13	26-03-2007	55	Outlet samples
	28-03-2007	57	Profiles
	30-03-2007	59	Outlet samples
14	02-04-2007	62	Outlet samples
	04-04-2007	64	Profiles
15	10-04-2007	70	Outlet samples
	12-04-2007	72	Profiles
	13-04-2007	73	Gas bottle 5
16	16-04-2007	76	Outlet samples
	20-04-2007	80	Outlet samples
17	24-04-2007	84	Profiles
	27-04-2007	87	Outlet samples
18	30-04-2007	90	Outlet samples
	03-05-2007	93	Outlet samples. Gas bottle 6
19	07-05-2007	97	Outlet samples
	11-05-2007	101	Profiles